Complications after aortic arch hybrid repair

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Objectives: **To analyze early and midterm complications after hybrid aortic arch repair (HAR).**
Methods: **Between January 1997 and November 2009 among 259 patients receiving thoracic endovascular aortic repair, HAR has been performed in 47 patients (median age, 64.5 years; range, 41-84). A retrospective analysis was performed. Complete supra-aortic debranching was performed in 15 patients (32%) and partial debranching in 23 patients (49%). Isolated left subclavian artery revascularization prior to thoracic endovascular aortic repair has been used in nine patients (19%). Emergency procedures were performed in 34% of all patients.**
Results: **The overall in-hospital mortality was 19% (9/47 patients), 27% after complete and 15.6% after partial debranching. Postoperative complications occurred in 32 patients (68%). Cardiocirculatory complications were observed in seven patients (15%). Pulmonary complications occurred in 12 patients (26%). A total of five patients (11%) experienced renal complications requiring hemodialysis. The stroke rate was 6.3%. Paraplegia was seen in three patients (6%). Proximal type I endoleaks were observed in seven patients. Retrograde aortic arch dissection was seen in three patients (6.3%). Cox proportional hazard regression showed the necessity for an emergency procedure as an independent predictor of death (hazard ratio, 2.9; 95% confidence interval, 1.1-7.5; *P* = .023). The reintervention rate was 27.6% with three patients requiring open conversion.**
Conclusions: **Hybrid aortic arch repair in high-risk patients is associated with a relevant morbidity, mortality, and reintervention rate. Patient selection is crucial and indication should be limited to patients not suitable for conventional aortic arch repair or emergency cases at present. Therefore, we recommend performing HAR only in high-volume centers with cardiovascular surgical cooperation.**

Vascular pathologies, involving the aortic arch, represent challenging cases for vascular and cardiovascular surgeons. Although the constant development of conventional open aortic arch replacement using extracorporal circulation, selective antegrade cerebral perfusion, and moderate hypothermia have led to improved results over years, it is still associated with a relevant morbidity and mortality rate.[1,2] Therefore, especially high-risk surgical patients may not be suitable candidates for open repair. As a consequence, thoracic endovascular aortic repair (TEVAR) as a potentially less invasive treatment has emerged over the last decade. To extend the proximal landing zone in the aortic arch, hybrid procedures that provide a sufficient landing zones and preserve cerebral perfusion are necessary.[3] These hybrid procedures combine an extra-anatomic supra-aortic debranching with endovascular exclusion of the pathology and can thus help to avoid sternotomy, single-lung ventilation, and aortic cross-clamping. The aortic arch thereby represents a morphologically challenging region. This is based on anatomic considerations (eg, proximity of the supra-aortic vessels, steep angulation of the aortic arch) as well as physiologic aspects (vulnerability of the aortic wall, pulsatile movements of the aorta). Complications of TEVAR in the aortic arch thus include proximal type I endoleckage, retrograde dissection, or stroke. Additionally, the necessary rerouting procedures (especially complete supra-aortic debranching) are associated with a significant mortality and morbidity rate.

The aim of this study was to analyze our results of hybrid aortic arch repair (HAR) focusing on incidence and causes of short- and midterm complications.

METHODS

Patient population. Between January 1997 and November 2009 among 259 patients receiving TEVAR in our institution, the aortic arch was involved in 101 patients. Aortic arch hybrid procedures have been performed in 47 of these patients (median age, 64.5 years; range, 41-84), which represents the total study population. An intention-to-treat analysis was performed including six patients who received debranching procedures only but no stent graft placement for various reasons (explained in detail in the results section). Baseline characteristics of all patients are presented in Table I.

Indications for treatment included 14 patients with a thoracic aortic aneurysm (TAA), 10 patients with a chronic expanding aortic dissection (CEAD) type Stanford B, eight patients with a thoracoabdominal aortic aneurysm (TAAA), seven patients with a penetrating aortic ulcer/intramural hematoma (IMH), five patients with an acute, complicated aortic dissection (ADB) type Stanford B, and three patients with patch aneurysms/rupture after previous surgical correction of an aortic coarctation.

Left subclavian artery (LSA) revascularization prior or simultaneous to TEVAR was only performed in selected

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Table I. Baseline characteristics of all patients with aortic arch hybrid procedures (n = 47)

Age (years)	64 (41-84)
Gender (male)	33 (70)
ASA III+IV	47 (100)
log Euroscore	31 (5-84)
Hypertension	46 (97)
History of smoking	15 (32)
CHD	19 (40)
Previous myocardial infarction	10 (21)
Renal insufficiency	10 (21)
COPD	17 (36)
Diabetes	5 (11)
Previous aortic surgery	16 (34)
Emergency cases	16 (34)

CHD, Coronary heart disease; *COPD,* chronic obstructive pulmonary disease.
Values are presented as median (range) or n (%).

patients. Our selection criteria and experience has already been published.[4]

In this study, only patients with prior or simultaneous LSA revascularization that were initially planned as hybrid procedures were included. Patients with secondary LSA revascularization due to arm claudication or subclavian steal syndrome after TEVAR were excluded.

Procedure. All surgical procedures were performed in an operation theater equipped with fluoroscopic and angiographic capabilities (Series 9800; OEC Medical Systems, Inc, Salt Lake City, Utah until April 2007, after that Axiom U; Siemens, Forchheim, Germany) and a carbon fiber operating table by a dedicated team of vascular surgeons. The procedure protocol has been published before.[5] All procedures were performed under general anesthesia, except for one patient that received TEVAR under regional anesthesia. For exact stent graft positioning in the aortic arch, our treatment concept involves some sort of cardiocirculatory arrest, especially in patients with a proximal landing zone 0 to 1. Initially, adenosine-induced cardiac arrest was used for this purpose and applied in 28 patients. After experiencing adenosine nonresponse in one patient (hypotonia was used in this patient), we changed to rapid pacing, which was used in another four patients.

Vascular access to the common femoral artery was obtained by inguinal cut down in 30 patients, via a Dacron conduit prosthesis sutured to the left common iliac artery in nine patients and via an aortic conduit in four patients (×3 infrarenal aorta, ×1 descending aorta).

Hybrid procedures. Complete supra-aortic vessel debranching, using a bi-/trifurcated Dacron graft originating from the ascending aorta to the supra-aortic vessels was performed in 15 patients (32%). No patient in this cohort underwent replacement of the ascending aorta. Partial supra-aortic vessel debranching with carotid–carotid cross-over bypass was used in 23 patients (49%). Additional revascularization of the left subclavian artery was performed in 16 out of these 23 patients. Isolated left subclavian artery revascularization via subclavian transposition or carotid–subclavian bypass prior to or simultaneous with TEVAR has been used in nine patients (19%). Additional visceral aortic hybrid procedures were performed in 6 (5/6 performed metachronously) out of 47 patients (13%). This includes three patients with partial and three patients with complete supra-aortic debranching. Our experience with visceral hybrid procedures has already been published.[6,7] Debranching and staged TEVAR has been performed in 50% of the patients with a median interval of 27 days (range, 4-126 days) between debranching and stent graft placement. In elective cases, we prefer a staged approach and perform an interval computed tomography angiography (CTA) between the debranching procedure and TEVAR (Fig 1). Spinal fluid drainage was used for selected patients at increased risk for paraplegia (eg, long covered aortic segment, previous infrarenal/thoracic aortic surgery). Neuromonitoring during debranching was performed using somatosensory evoked potentials and transcranial Doppler. Selective shunting was applied.

Four different commercially available devices were implanted: ×2 TAG/C - TAG (W. L. Gore and Associates, Flagstaff, Ariz), ×12 Talent/Valiant (Medtronic Vascular, Santa Rosa, Calif), ×3 Endofit (LeMaitre Vascular, Burlington, Mass), and ×3 Zenith (Cook Inc, Bloomington, Ind). Whenever available, stent graft sizing was based on preoperative centerline measurements.[8]

Follow-up. The follow-up protocol included postoperative CTA before discharge, clinical examination, plain chest radiography and CTA/MRA 6 and 12 months postoperatively and annually thereafter. Additionally, duplex scanning to exclude bypass stenosis or occlusion was performed. Mean follow-up was 21.4 months (range, 0.1-96.9 months) with four patients lost in follow-up (three patients refused serial aortic imaging and one patient could not be located).

Definitions and statistical analysis. Technical success was defined according to the reporting standards for endovascular aortic aneurysm repair.[9] Endoleaks were categorized as described by White, et al[10] and specified as early endoleaks if apparent on intraoperative control angiography or primary postoperative CTA control. Late endoleaks were defined as occurring during follow-up. Pulmonary complications were defined as occurrence of pneumonia, pulmonary edema, or necessity for reintubation/prolonged (>2 days) mechanical ventilation. Renal failure was considered if temporary or permanent hemodialysis was required.

In patients receiving metachronous procedures, complications related to the debranching procedure were defined as stage I and complications related to TEVAR as stage II. Complications in patients receiving simultaneous procedures were categorized as stage II. Complete debranching was defined as revascularization of at least the inominate artery and the left carotid artery via bypass from the ascending aorta. A retrospective analysis of the prospectively collected data was performed. Data are expressed as mean ± SD or median (range). Survival rates were estimated by Kaplan-Meier. Cox proportional hazard model (Cox regression analysis) was used to identify independent

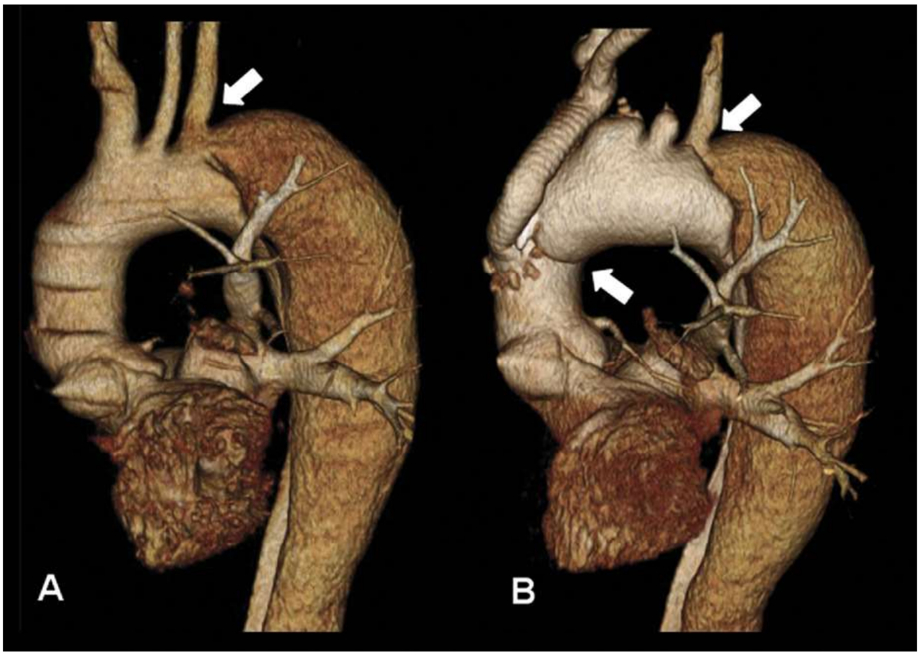

Fig 1. Three-dimensional volume rendering of computed tomography angiographies showing a **(A)** preoperative chronic expanding aortic dissection type B (*entry tear: white arrow*) and **(B)** retrograde type A dissection after complete debranching (*white arrows*).

Table II. In-hospital mortality of all patients with aortic arch hybrid procedures (n = 47)

	Total (n = 47)	*Complete debranching (n = 15)*	*Partial debranching (n = 32)*	*Arch and visceral hybrid procedures (n = 6)*
Mortality stage I	4 (6.3%)	3 (20%)	1 (3.1%)	
Causes of death				
Myocardial infarction		1	—	
Pneumonia		1	—	
Stroke		—	1	
Unknown		1	—	
Mortality stage II	5 (10.6%)	1 (6.6%)	3 (9.3%)	1 (16.6%)
Causes of death				
Multiorgan failure		1	1	1
ICB		—	2	—
In-hospital mortality	9 (19%)	4 (27%)	5 (15.6%)	1 (16.6%)

ICB, Intracerebral hemorrhage.

risk factors affecting survival. All statistical analyses were performed using XLSTAT (Version 7.5; Addinsoft SARL, New York, NY) or MedCalc (Version 9.5.2; MedCalc software, Mariakerke, Belgium).

RESULTS

Early outcomes

Mortality. The overall in-hospital mortality was 19% (9/47 patients), 27% (4/15 patients) after complete debranching, and 15.6% (5/32 patients) after partial debranching. Causes of death in these nine patients were multiorgan failure in three patients (Table II). Lethal intracerebral hemorrhage (ICB) was observed in two patients, including one patient with an ICB on day 11 after partial debranching and TEVAR (initial postoperative uneventful), and one patient with a cerebellar hemorrhage on day 25 after open conversion due to intraoperative retrograde aortic arch dissection.

A total of 4/47 patients (6.3%) died after supra-aortic debranching before staged, planed TEVAR could be performed. Causes of death included pneumonia, stroke, and myocardial infarction. One patient died unexpectedly on the second postoperative day after complete debranching (initial postoperative course completely uneventful). The actual cause of death remained unclear since an autopsy was denied by the relatives.

Elective vs emergency procedures. Results for elective versus emergency procedures are shown in Table III.

Table III. In-hospital mortality of emergency (n = 16) vs elective (n = 31) aortic arch hybrid procedures

Variable	*Complete debranching*	*Partial debranching*	*Total*
Emergency	2/4 (50%)	3/12 (25%)	5/16 (31%)
Elective	2/11 (18%)	2/20 (10%)	4/31 (13%)

Table IV. Risk factor analysis regarding perioperative death (Cox regression analysis)

Variable	*Hazard ratio*	*95% CI*	P *value*
Emergency procedure	2.9	1.1-7.5	.023
Complete debranching	1.58	0.59-4.2	.361

CI, Confidence interval.

Cox proportional hazard regression showed the necessity for an emergency procedure as an independent predictor of death. A complete debranching procedure did not influence survival in this series (Table IV).

Morbidity. Postoperative complications occurred in 32 patients (68%), with five patients experiencing isolated minor (wound/lymphatic) complications.

Complications stage I (Table V). A total of eight patients (17%) experienced complications at this stage of the procedure. The majority of complications (7/8 patients) occurred after complete debranching and included cardiac (myocardial infarction, hemodynamic relevant arrhythmia requiring electrical cardioversion, temporary cardiocirculatory arrest) and pulmonary complications. Stroke with a consecutive lethal cerebral edema was observed in one patient after partial debranching. One patient developed an acute-on-chronic renal failure and required temporary hemodialysis. Retrograde dissection was observed in one patient (see retrograde dissection section below).

Complications stage II (Table V). A total of 24 patients (51%) experienced complications at this stage of the procedure, with an increasing incidence from complete (33%) to partial (47%) to combined arch and visceral hybrid procedures (67%). Cardiac complications included myocardial infarction, hypertensive crisis (consecutive temporary left heart failure with pulmonary edema), and temporary cardiocirculatory arrest (two patients). Renal complications were observed in five patients, including three patients with combined visceral/aortic arch hybrid procedures showing renal failure after visceral debranching (×1 permanent hemodialysis) and two patients with a temporary acute renal failure. Perioperative stroke occurred in two patients after simultaneous partial debranching and TEVAR. Lethal intracerebral hemorrhage was seen in two patients (described above). Permanent paraplegia was observed in three patients (6%). This was related to an acute, complicated (paraplegia) aortic dissection type Stanford B in one patient. One patient showed paraplegia after emergency conversion due to a retrograde dissection, and one patient suffered paraplegia after simultaneous visceral and arch hybrid procedure.

Endoleaks. Proximal type I endoleaks were observed in seven patients (×6 primary endoleaks, ×1 secondary endoleak). Six out of these seven patients received a reintervention (×4 further debranching and proximal stent graft extension, ×2 proximal stent graft extension) that sealed the endoleaks in five patients. One patient showed a small, persistent type Ia endoleak despite stent graft extension. The patient has been under close CTA surveillance for 3 years without signs of expansion. One out of seven patients was referred for open conversion since the endoprosthesis could not be placed more proximally in the aortic arch due to a heavy angulation of the aortic arch, but open conversion was denied in this high-risk patient. An endoleak type II was observed in four patients (×3 LSA, ×1 bronchial artery), which spontaneously sealed in two patients. One patient received a subclavian transposition and one patient is under CTA control.

Retrograde aortic dissection. Retrograde aortic dissection was observed in three patients (6.3%). One patient (50 years, chronic expanding type B aortic dissection) showed a retrograde aortic dissection after complete aortic arch debranching on the first postoperative CTA[11] (Fig 1). Therefore, TEVAR was denied and open aortic arch replacement using the frozen elephant trunk technique was performed. The postoperative course was uneventful. Retrospectively, a clamp injury at the ascending aorta with resulting dissection was the suspected reason. The second patient (65 years, chronic expanding type B aortic dissection) experienced an intraoperative retrograde aortic dissection during TEVAR. The patient initially had received subclavian transposition prior to the endograft placement. During TEVAR, a proximal dislocation of the endoprosthesis with partial coverage of the left common carotid artery occurred, and a stent graft placement in chimney technique as a bailout procedure was attempted. During this procedure, a retrograde dissection in the ascending aorta, possibly related to the wire manipulation, was visualized on transesophageal echocardiography. The patient underwent immediate open conversion. Intraoperatively, partial occlusion of the left common carotid artery by the endograft was verified. During the postoperative course, the patient experienced paraplegia and died of an intracerebral hemorrhage, possibly related to cerebrospinal fluid drainage. During follow-up, a third patient (64 years, chronic expanding type B aortic dissection) experienced retrograde aortic dissection in the proximal aortic arch with a major stroke 5 years after partial debranching and TEVAR. The patient was denied open arch repair and died in the sequel of this persistent neurological deficit.

Bypass occlusion. No early bypass occlusion was observed. During follow-up, one patient developed an asymptomatic, retrosternal compression of an ascending carotid (left common carotid artery) bypass 2 years after complete debranching (Fig 2). Bypass correction with carotid–carotid cross-over bypass was performed. A second patient experienced an asymptomatic bypass occlusion of a

Table V. Early and midterm complications of all patients with aortic arch hybrid procedures (n = 47)

	Total (n = 47)	*Complete debranching (n = 15)*	*Partial debranching (n = 32)*	*Arch and visceral hybrid procedures (n = 6)*
Morbidity stage I	8 (17%)	7 (47%)	1 (3%)	—
Cardiac complications	3	3	—	—
Pulmonary complications	2	2	—	—
Renal failure	1	1	—	—
Stroke	1	—	1	—
Retrograde dissection	1	1	—	—
Morbidity stage II	24 (51%)	5 (33%)	15 (47%)	4 (67%)
Cardiac complications	4	2	2	—
Pulmonary complications	10	2	7	1
Renal failure	5	1	1	3
Stroke	2	—	1	1
ICB	2	—	2	—
Paraplegia	3	—	2	1
Retrograde dissection	1	—	1	—
Wound/lymphatic complication	5	3	2	—
Primary type IA endoleak	6 (13%)	—	5 (17%)	1 (17%)
In-hospital morbidity	32 (68%)	12 (80%)	16 (50%)	4 (67%)
Midterm complications				
Retrograde dissection	—	—	—	1
Bypass stenosis/occlusion	—	—	2	—

ICB, Intracerebral hemorrhage.

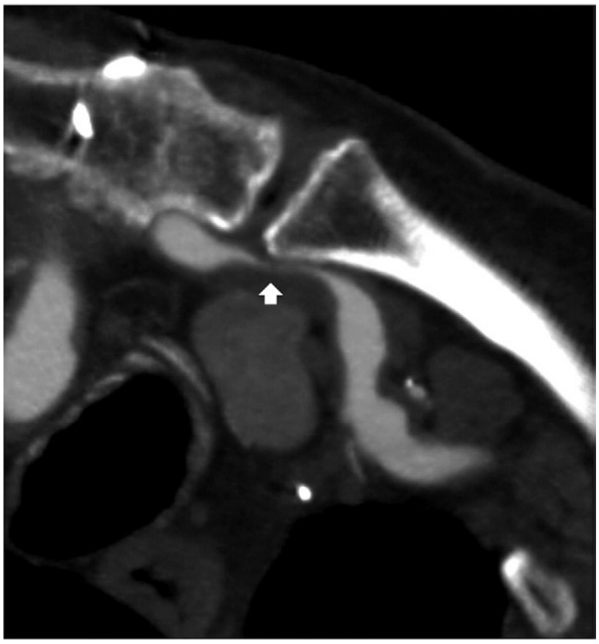

Fig 2. Control computed tomography angiography showing a retrosternal bypass compression (*white arrow*) 2 years after complete debranching.

carotid–carotid cross-over bypass with a still-patent internal carotid artery via cross-flow. A new carotid–carotid cross-over bypass was performed.

Intention to treat

The hybrid procedure could not be completed in six patients, which includes three patients that died after the debranching procedure and one patient that experienced a retrograde dissection after complete rerouting and received open conversion. Two patients showed an extremely kinked aorta with a steep aortic arch and we were not able to deliver the endograft into the aortic arch despite an additional brachial access. One patient (50 years, pseudoaneurysm after surgical correction of an aortic coarctation) received conventional aortic arch repair and is currently alive 2 years after the operation. The second patient was denied open repair and died 8 months after the failed hybrid repair for unknown reason.

Late outcomes

The Kaplan-Meier survival estimates at 1 and 3 years were 77% ± 6% and 59% ± 8%, respectively (Fig 3). Causes of late death were stroke/intracerebral hemorrhage in three patients, myocardial infarction in one patient, and pneumonia in one patient. Aortic-related death occurred in two patients. One 81-year-old patient died of an ascending aortic rupture two and a half years postoperatively after a successful aortic arch hybrid procedure for a TAA. Open cardiac surgery with replacement of the ascending aorta was denied in this highly comorbid patient. One patient died of a retrograde aortic dissection (described above). One patient died of an unknown reason 8 months postoperatively. The overall reintervention rate was 27.6% (13 patients) with three patients (6.3%) requiring open conversion.

DISCUSSION

The present series shows that HAR, especially complete debranching procedures, is associated with a relevant mortality rate (19%). The analysis further revealed severe complications in a significant proportion of patients causing reintervention in approximately 25% of all patients.

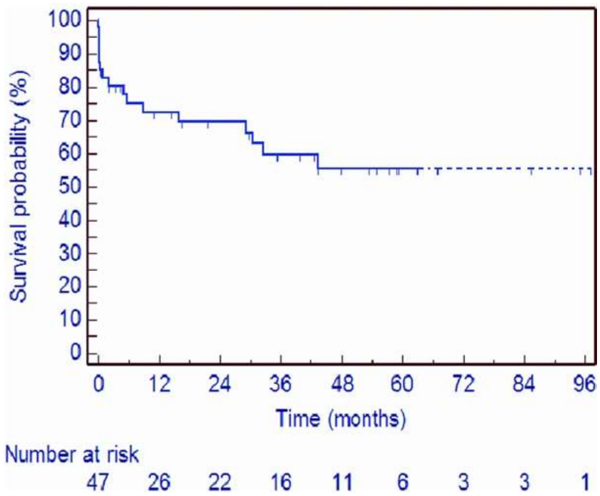

Fig 3. Kaplan-Meier survival analysis of all patients (n = 47) treated with aortic arch hybrid procedures.

The reported mortality rates after aortic arch hybrid procedures vary between 0% and 15.4% and are thus below our mortality rate.[12-17] A possible explanation could be significant differences in patient selection. At present, all series limit patient selection for hybrid procedures to high-risk patients "unfit" or "not suitable" for open aortic arch repair but definition of "high-risk" and comparable selection criteria of these patients (eg, Risc scores) are frequently missing. Czerny et al report a log Euroscore of 26 (range, 12-56) in their series of 27 patients with aortic arch hybrid repair that seems comparable to our series.[18] Their mortality rate of 7.4% is favorable to our results, but again, patient selection warrants attention. No emergency cases were included in their series (all stent grafts placed metachronously) compared with 34% emergency procedures in our series, which influenced perioperative survival (hazard ratio, 2.9; $P = .023$) Additionally, the underlying pathologies (eg, the percentage of acute, complicated type B dissection) and the amount (17%-60%) of complete debranching procedures (32% in this series) vary significantly and make comparison of the few available larger series difficult. In this series, complete debranching procedures showed a higher mortality rate (27% vs 15.6%), although this did not reach statistical significance ($P = .36$), possibly caused by the still relatively small amount of patients. Our patient selection initially involved only "high-risk patients" for hybrid procedures, but we expanded our indications after early promising results.[3,19] At present, after experiencing serious complications in a viable amount of patients as described in this series, a very strict (meaning not suitable/denied for open repair) patient selection has been restored. At present, approximately 60% of aortic arch hybrid procedures are performed simultaneously and no evidence-based recommendation regarding temporal tactics exist so far.[20,21] We prefer a staged approach in elective cases, but due to the small numbers in both groups (simultaneous vs staged), a valuable comparison regarding outcome is questionable, especially as all simultaneously performed emergency cases (which showed a worse outcome) could bias this analysis.

Retrograde aortic dissection was observed in a significant proportion of patients (6.3%) in this series. This is above the reported incidence of 1.3% after TEVAR, but explicable as the analysis from the "European registry on endovascular aortic repair complications" included TEVAR in all aortic segments.[22] Reasons for this complication in our series (three patients) included clamp damage at the ascending aorta during complete debranching, stiff guidewire/nose cone manipulation in the aortic arch and disease progression. The underlying pathology was a type B dissection in all cases, which is in line with Eggebrecht et al who showed these patients to be most prone for the occurrence of retrograde dissection.[22] Management of this complication consists of urgent open surgical conversion, which makes cardiosurgical back-up for aortic arch hybrid procedures in our opinion inevitable.

Delivery of the stent graft into the aortic arch, and thus completion of the hybrid procedure, was not possible in two cases in this series due to a heavily kinked aorta with a steep arch angulation. A possible solution for this problem includes an additional transbrachial access or antegrade deployment, which both failed in these cases. In our experience, especially young patients with previous open aortic arch surgery (eg, for aortic coarctation) present with this challenging anatomy and warrant special considerations.

Stroke rates after arch hybrid repair vary between 0% and 8% in the literature and are thus in line with the stroke rate of 6.3% in this study.[14,23] Reasons for stroke include clamping/embolism formation during the rerouting procedure or manipulation in the diseased aortic arch during TEVAR. The incidence of spinal cord injury after isolated aortic arch hybrid procedure is low (0%-4%).[23,24] Frequently, the reported cases of paraplegia are associated with a concomitant visceral hybrid procedure and long covered aortic segment, as also seen in our series.[25]

Bypass occlusion/stenosis is a rare, but described complication and occurred in two patients in this series. We therefore perform routine bypass duplex ultrasound during follow-up.

The Achilles' heel of endografting in the aortic arch remains the development of proximal type I endoleaks with a reported incidence of 0%-25% (15% in this series) leading to further reinterventions.[14,15,24,26] Reasons include a short landing zone (<2 cm), which might have been accepted in a first approach (especially emergency cases) to avoid sternotomy and complete debranching in these high-risk patients. In our series, 5/6 proximal type I endoleaks were seen after partial debranching and 4/6 were sealed with further debranching and proximal stent graft extension. Additionally, the recently available stent grafts are not designed especially for the aortic arch and miss conformability at the inner curve (bird beak sign). This is especially prevalent in patients with a steep aortic arch and the mid-aortic arch section.

CONCLUSION

Aortic arch hybrid procedures show a variety of severe complications associated with a relevant morbidity, mortality, and reintervention rate and should therefore only be performed in high-volume centers with cardiosurgical back-up. Patient selection is crucial in these cases and indication should be limited to patients not suitable for conventional aortic arch repair. Off-the-shelf, single-branched endoprosthesis may represent the future solution in the aortic arch to avoid complete debranching and possibly reduce morbidity and mortality of HAR.

AUTHOR CONTRIBUTIONS

Conception and design: PG, DK
Analysis and interpretation: PG, DB, AD
Data collection: DK, AD, MM
Writing the article: PG, DK
Critical revision of the article: DB, DK, MM
Final approval of the article: PG, DB
Statistical analysis: PG, DK
Obtained funding: Not applicable
Overall responsibility: DB, PG, DK
PG and DK contributed equally to this work.

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